

HYCOM code development

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2003 Layered Ocean Model Users' Workshop

February 10, 2003

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 10 FEB 2003		2. REPORT TYPE		3. DATES COVERED 00-00-2003 to 00-00-2003	
4. TITLE AND SUBTITLE HYCOM code development				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory,Stennis Space Center,MS,39529				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES Layered Ocean Modeling Workshop (LOM 2003), Miami, FL, Feb 2003					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 36	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

HYCOM 2.1.03 (I)

- First public release of HYCOM 2.1
 - September, 2001
- Maintain all features of HYCOM 2.0
 - Requires Fortran 90
 - Can use HYCOM for pure iso-pycnal cases
 - KPP or Kraus-Turner mixed-layer
 - Energy-Loan (passive) ice model
 - High frequency atmospheric forcing
 - New I/O scheme (.a and .b files)
 - Scalability via OpenMP or MPI or both
 - * Bit-for-bit multi-cpu reproducibility

HYCOM 2.1.03 (II)

- Orthogonal curvilinear grids
- Fully global domains
 - Near-global Mercator already in HYCOM 2.0
 - Pan-Am grid with closed Bering Strait
 - * Open Bering Strait requires a special halo exchange
 - * Available “soon”
- Multiple tracers
 - Passive
 - Simple biology (NPZ or NPZD)
 - * Most of infrastructure in place
 - * More work needed on biology and boundary conditions
- Rivers as bogused surface precipitation
 - Annual or monthly climatology

HYCOM 2.1.03 (III)

- Off-line one-way nesting
 - Similar to MICOM
 - * Exact b.c. for depth averaged component
 - * Relaxation for 3-D T/S/pressure/velocity
 - Based on relaxation to climatology
 - But with addition of velocity relaxation
 - Interpolate to target domain off-line
 - * Source domain to target domain archive files
 - * Nested model does not “know” about enclosing domain
 - * Can discard deep iso-pycnal layers
 - * Can remap to new vertical coordinate
 - Get boundary data from input archive files
 - * Simplifies scalability
 - * At the cost of more I/O and bigger files
- Same resolution nesting unexpectedly useful
 - No need to rerun large domain
 - Change atmospheric forcing (e.g. use MM5)
 - Change vertical structure
 - Tracer studies (e.g. add biology)

HYCOM 2.1.03 (IV)

- More general fixed (sigma/Z) vertical coordinate
 - Emulate Z or Sigma or Sigma-Z models
 - HYCOM has partial cells
 - * Emulate full cell Z models with the appropriate bathymetry
- Alternative mixed-layer models
 - Mellor-Yamada 2.5
 - Price-Weller-Pinkel
- Explicit support for 1-D and 2-D domains
 - Tiling allows periodic domains
 - 1-D is 2x2 doubly periodic domain
 - * Only read/write .b files
 - 2-D is Nx2 periodic domain
 - * Infinite f-plane

HYCOM 2.1 (V)

- Region-independent setup and diagnostics
 - Dynamic memory allocation
 - Compile once for all domains
 - Actual model code still domain-dependent
- Restart processing
 - HYCOM from MICOM
 - HYCOM from archive file
 - HYCOM from coarser resolution HYCOM
 - Change land/sea boundary
- Archive processing
 - Add/subtract/merge layers
 - Remap to new vertical coordinate
 - Mean and variability
 - Off-line sampling
 - * Vertical profiles
 - * Transport sections
 - To netCDF and other file formats
 - * All x-y “hycomproc” fields
 - * Interpolated to z-space

HYCOM FILE FORMAT

- MICOM's PAKK I/O not efficient or accurate
- HYCOM 2.1 reads/writes “.a and .b” files
 - “.a” is a raw IEEE REAL*4 array file (Fortran direct access)
 - “.b” is a plain-text header file (Fortran formatted)
- This I/O is simple and portable
- It can easily be parallelized
 - Have the N-th processor read/write every N-th 2-D array record
- Convert to netCDF off-line
 - Climate and Forecast (CF) conventions
 - * Extension of COARDS conventions
 - Supports curvilinear grids
 - * Most existing software is for COARDS only
 - Unlimited time dimension
 - * Simplifies time concatenation
 - Safest to have single field per file
 - * Avoids all 2GB limits

EQUAL AREA DOMAIN DECOMPOSITION

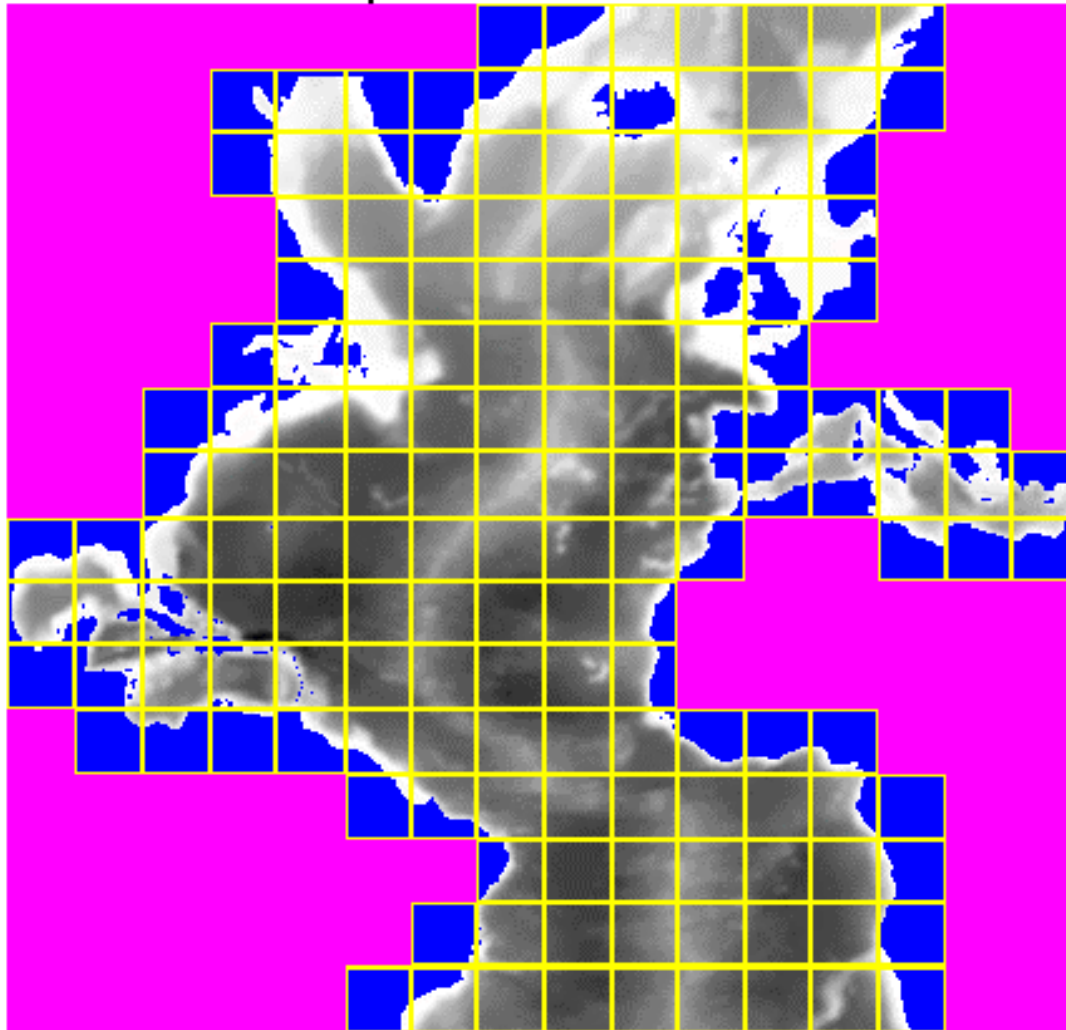
- Simplest domain decomposition is equal-sized rectangular tiles
 - Each tile has four neighbors
 - * Eight neighbors including halo corners
- Overall speed controlled by slowest tile
 - Probably have an “all ocean” tile
 - * no advantage to avoiding land within a tile
- Discard tiles that are entirely over land
 - Simple to implement
 - Does not discard all land
 - P-MICOM probably first ocean model to do this
 - Should be in all MPI-based OGCM's

IMPROVED DOMAIN DECOMPOSITION

- HYCOM 2.0 and 2.1 allows:
 - Discarded tiles
 - Variable tile size
 - Many North-South neighbors
- Equal-ocean tiling
 - First distribute one axis, then the other
 - Near perfect load balance
 - Some tiles require more memory than others
 - Aspect ratio of rectangle can be large
 - More expensive halo exchange
- Modified equal-area tiling
 - Discard all-land tiles
 - Shift tiles to fit coastline
 - Double-up tiles if less than half ocean
 - Compared to equal-area tiling:
 - * Up to 2x the memory requirement
 - * More expensive halo exchange
 - * Often significantly fewer tiles

MICOM 2-D DOMAIN DECOMPOSITION

2-D Equal-Sized Tiles for MPI



Each Tile has 4 neighbors

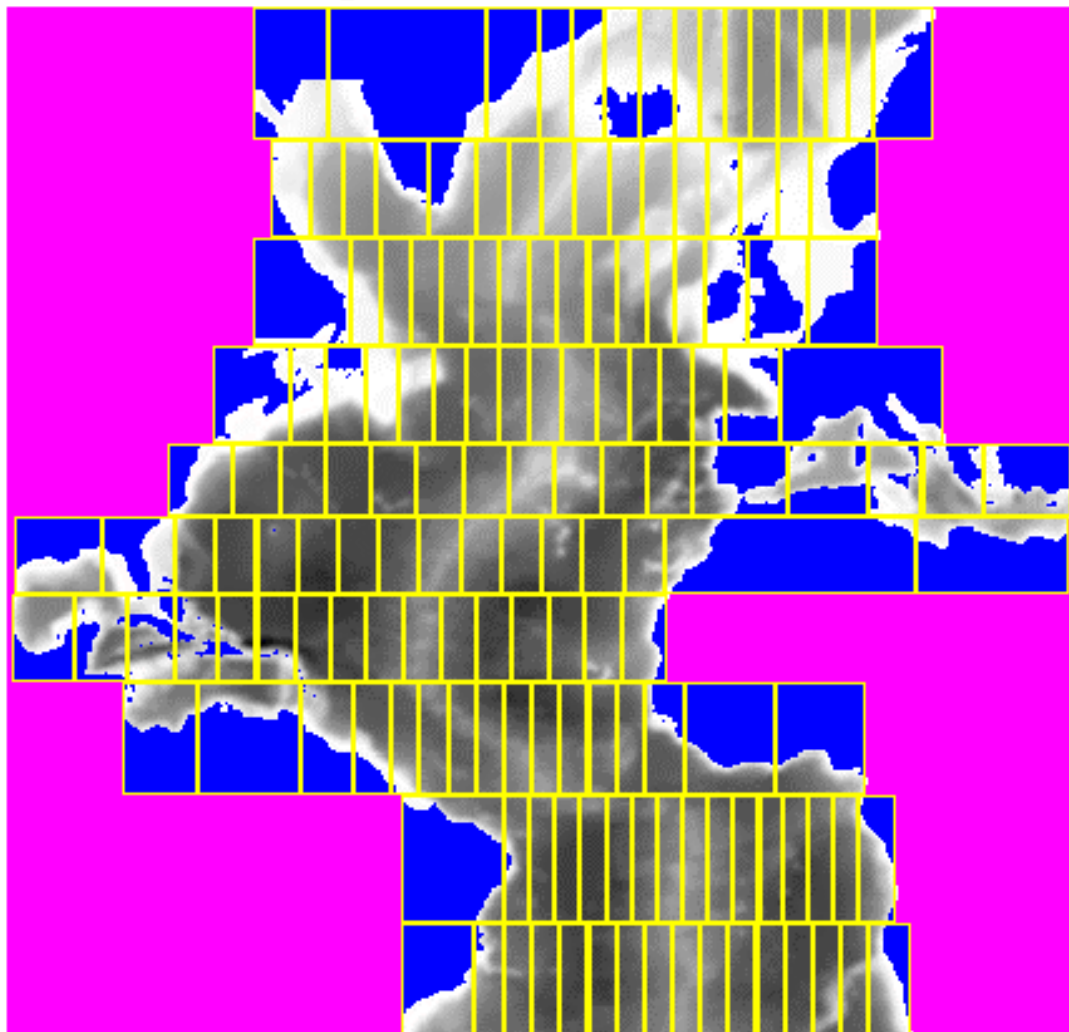
Discard “All-Land” Tiles

$16 \times 16 = 256$ Tiles but only 161 active

Still have significant load imbalance

HYCOM 2-D DOMAIN DECOMPOSITION

2-D “Equal Ocean” Tiles for MPI

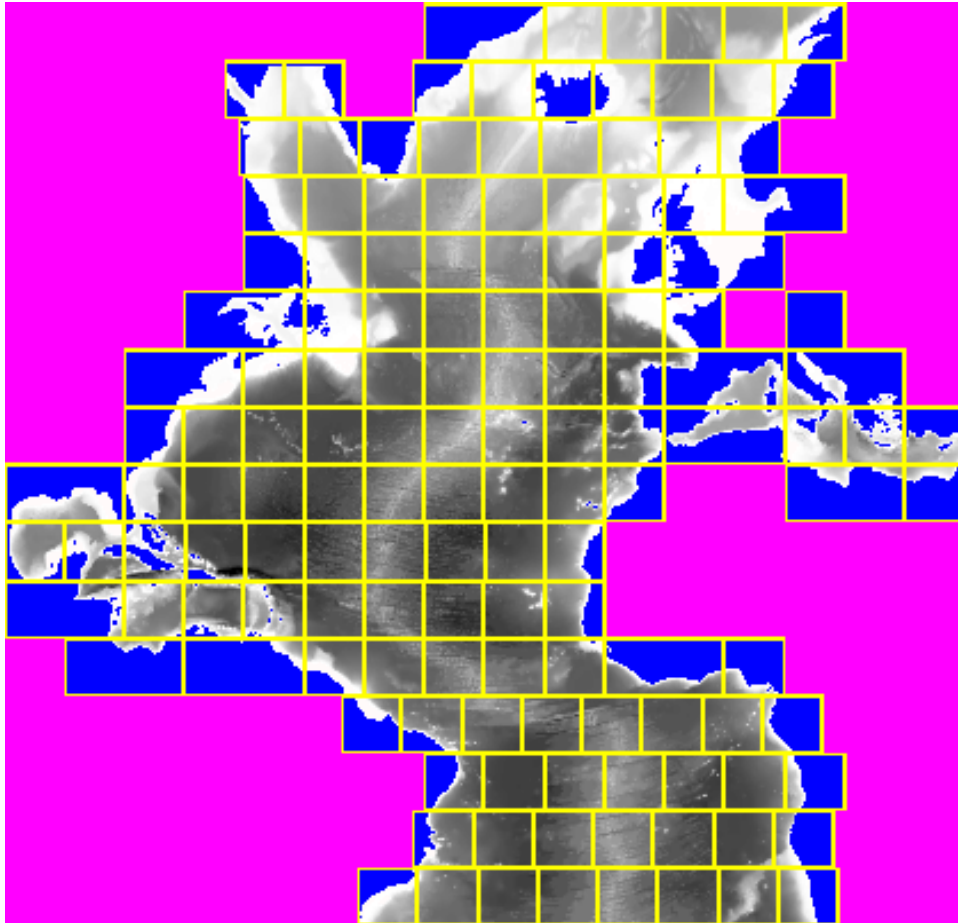


Each tile has 2 E–W neighbors, but many N–S
neighbors

Compared to 16 x 16 “equal – size” decomposition:
30% less work on “worst” tile
larger memory requirement

MODIFIED EQUAL AREA TILING

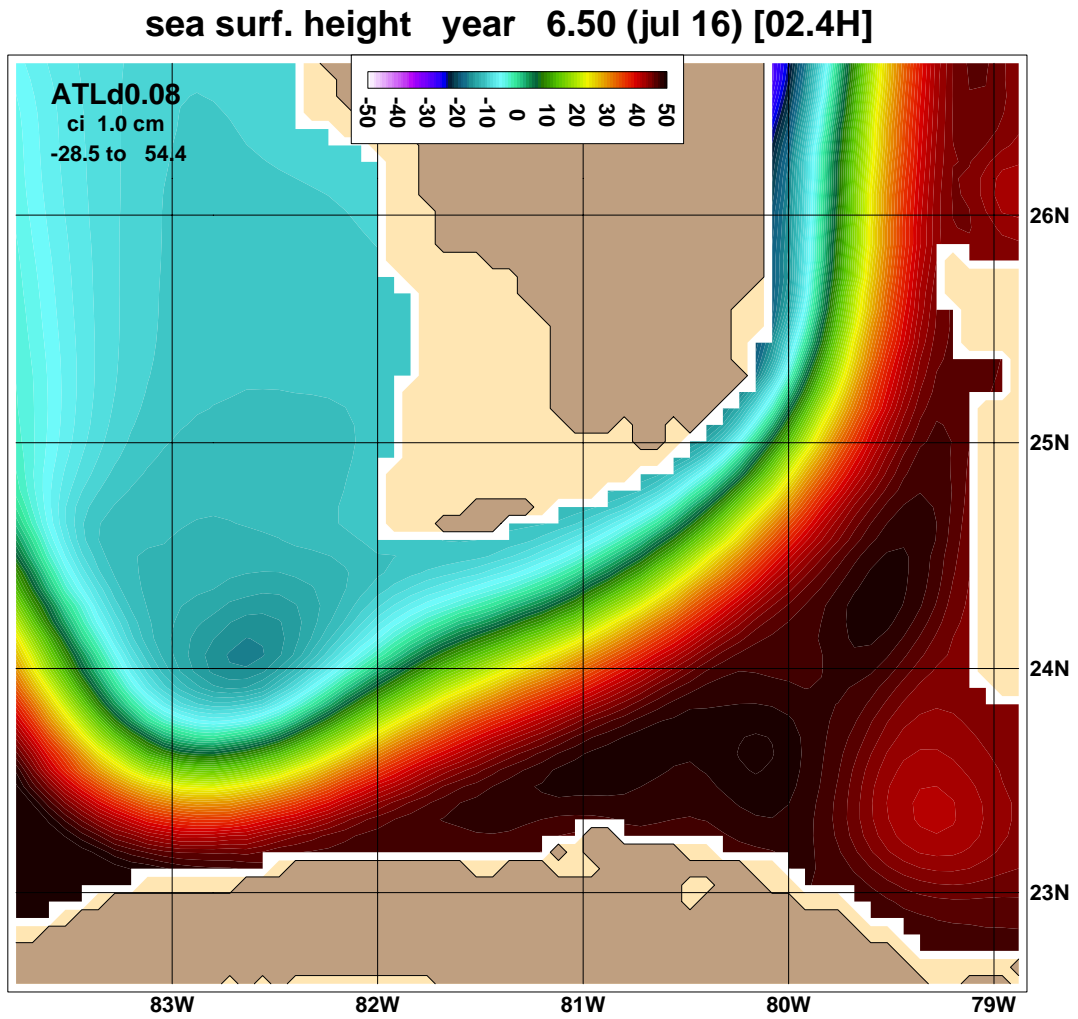
16x16 = 256 Tiles but only 143 Active
12% fewer than equal area tiling



NESTING EXAMPLE

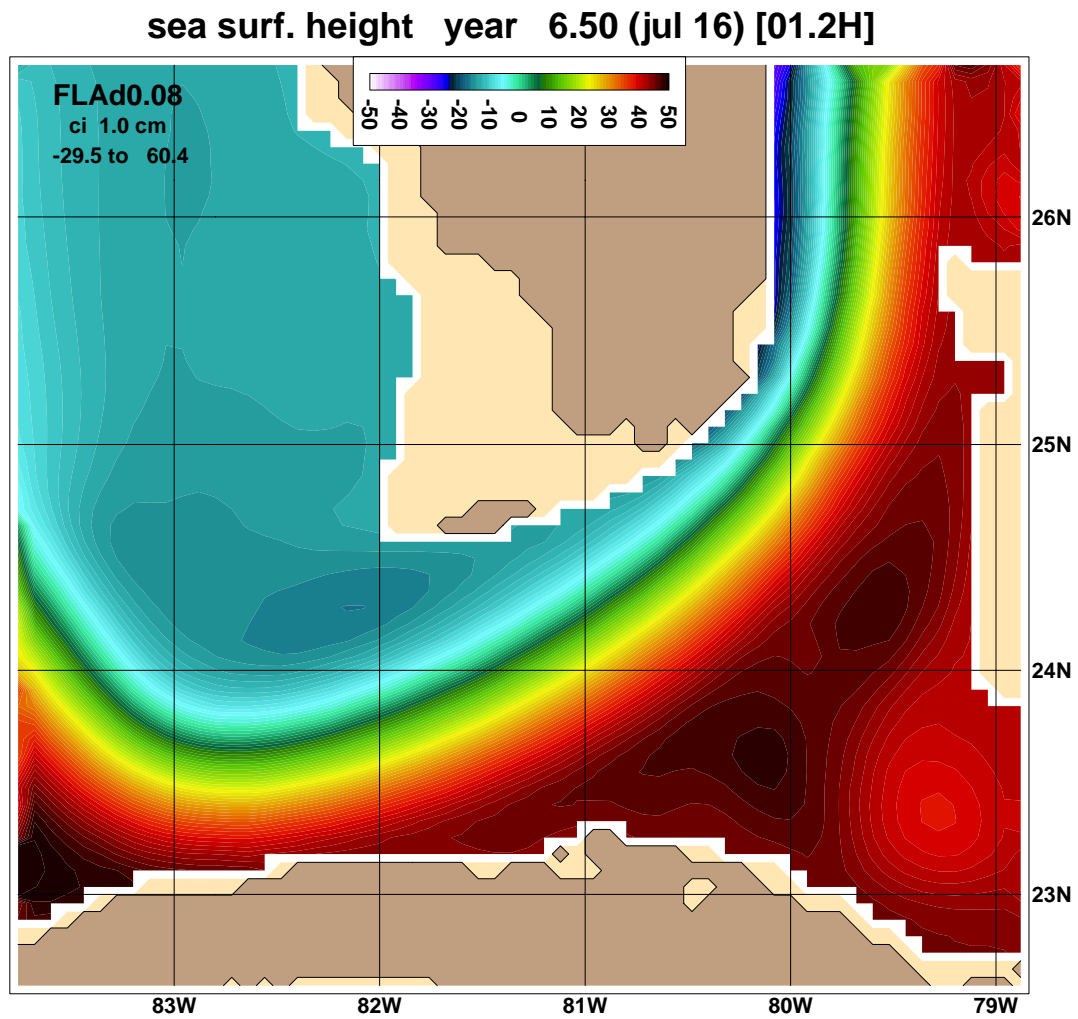
- Extract very small piece of 1/12 degree Atlantic
 - Florida Straits only
 - 1.8 m/s surface intensified flow
 - about 30 Sv total transport
- Same grid resolution
 - Can run on a workstation
 - Intent is to add biological tracers
- Based on previous test cases, started with
 - 1-day depth averaged Atlantic sampling
 - 6-day 3-D Atlantic sampling
 - T/S/p relaxation, with 1-day e-folding
- 1-day e-folding increased 10x
- Added u/v/T/S/p relaxation
- Probably need 1-day 3-D sampling

ORIGINAL FSD AFTER 180 DAYS

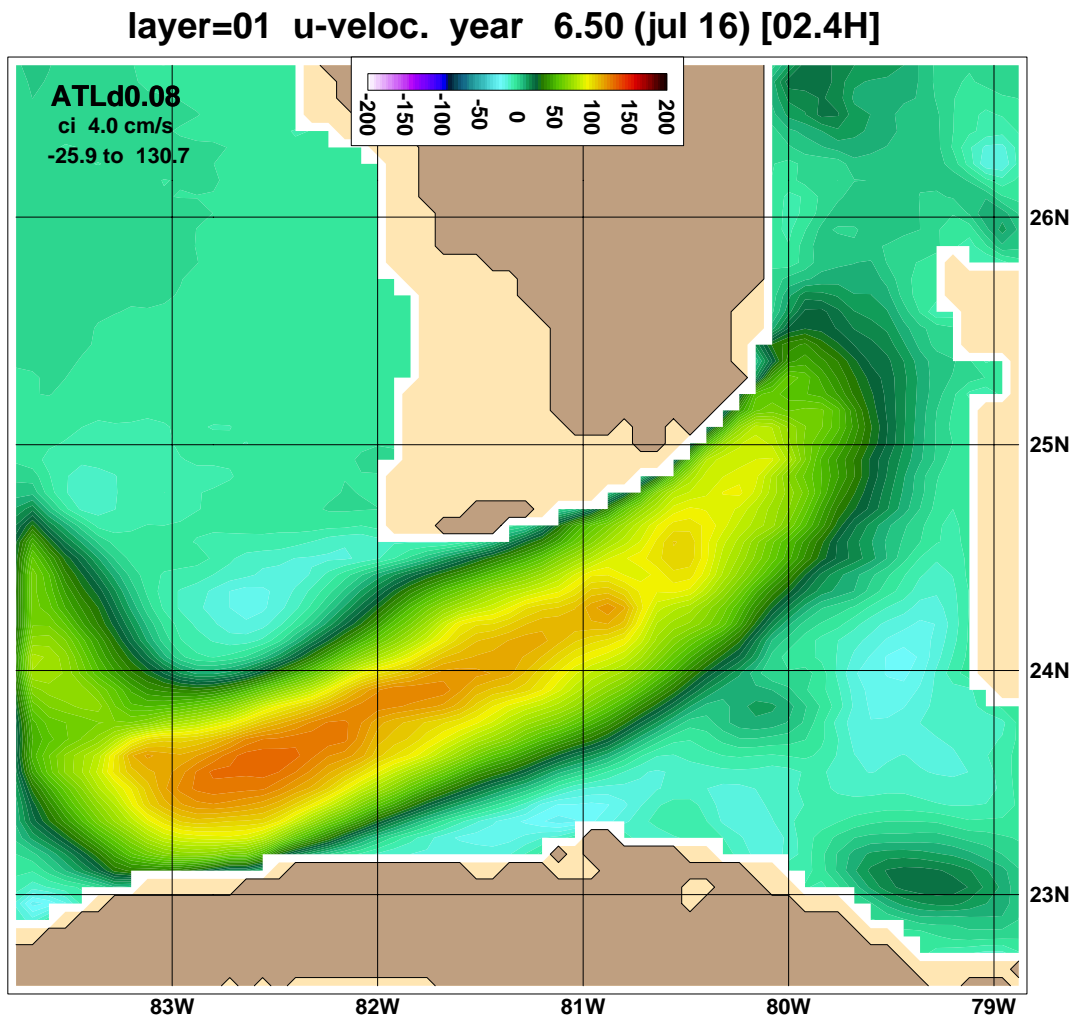


NESTED FSD AFTER 180 DAYS

0.1-DAY E-FOLD T-S-p-u-v RELAX

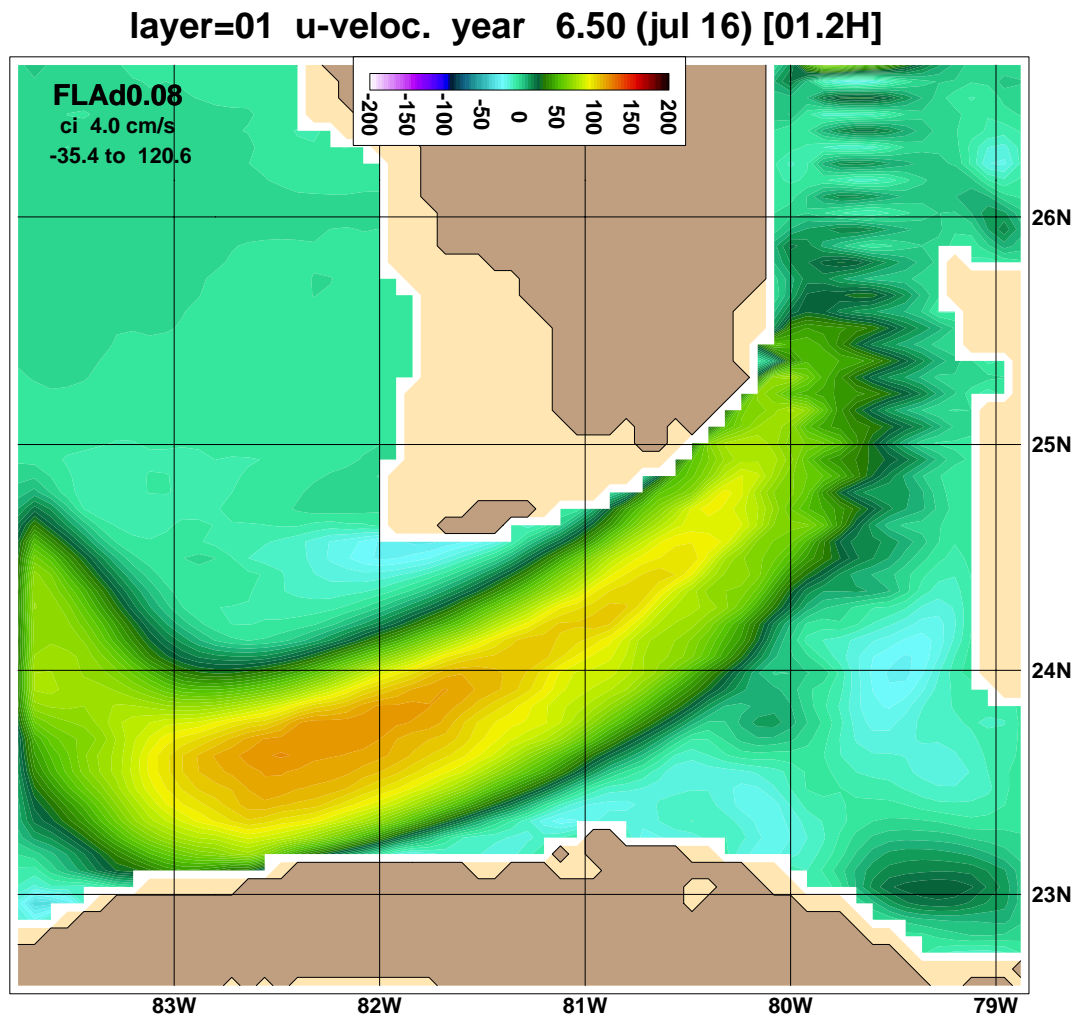


ORIGINAL U-VELOCITY AFTER 180 DAYS

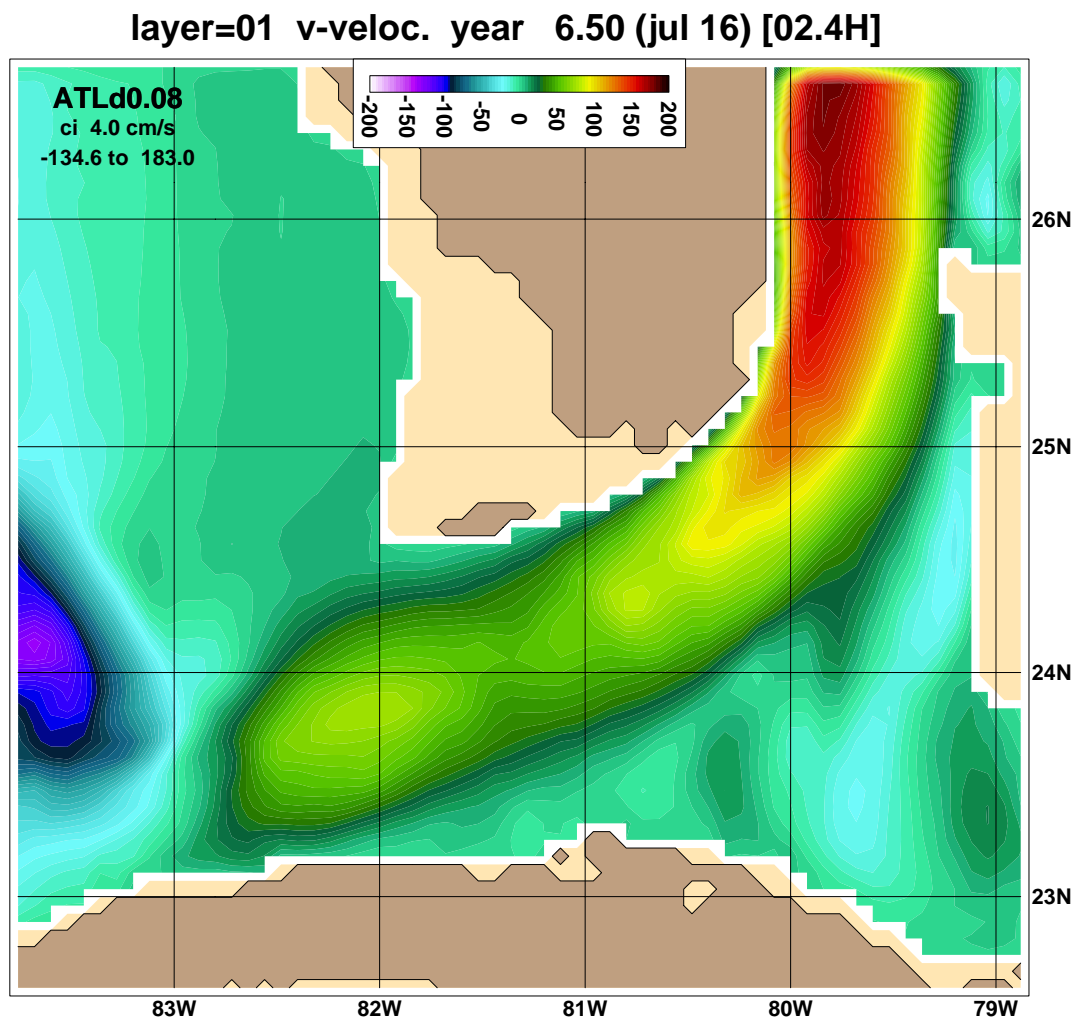


NESTED U-VELOCITY AFTER 180 DAYS

0.1-DAY E-FOLD T-S-p-u-v RELAX

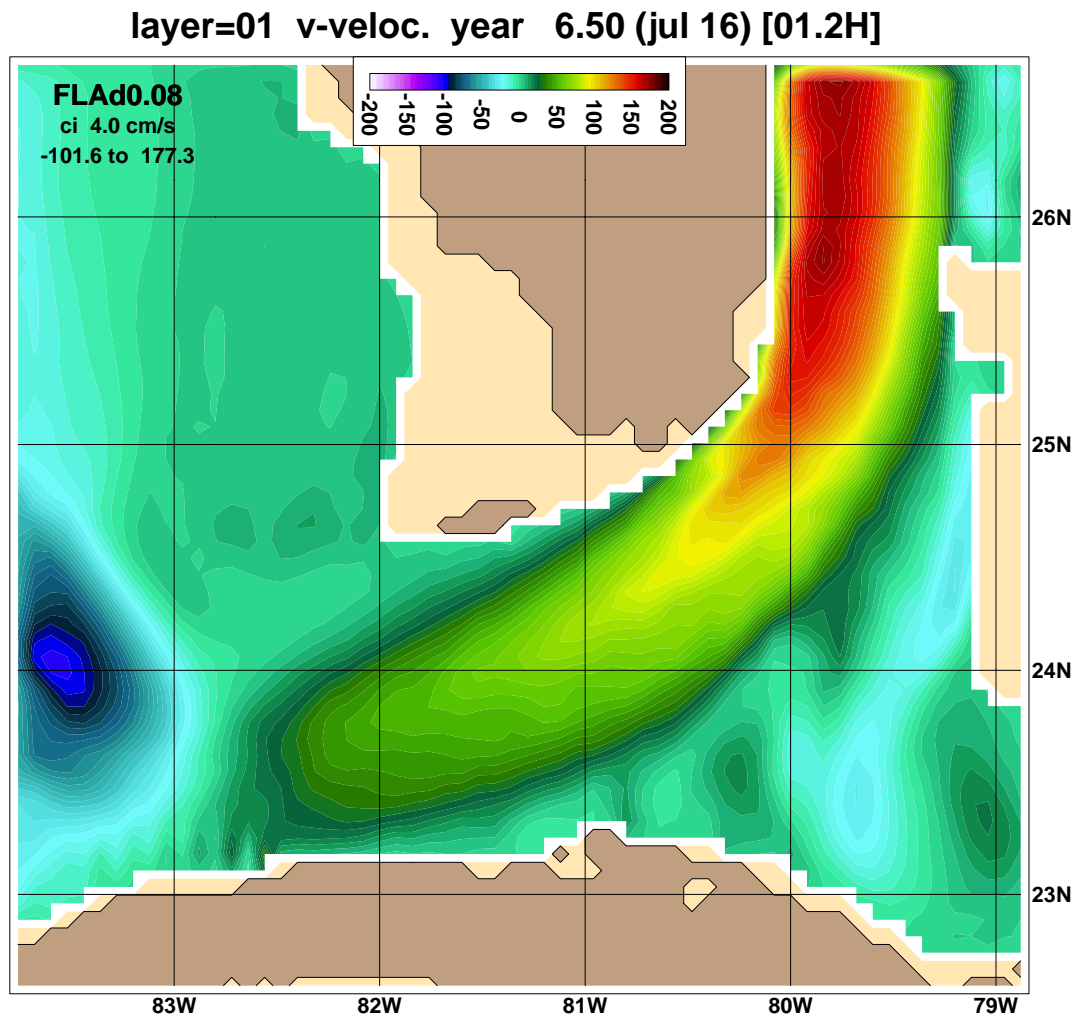


ORIGINAL V-VELOCITY AFTER 180 DAYS



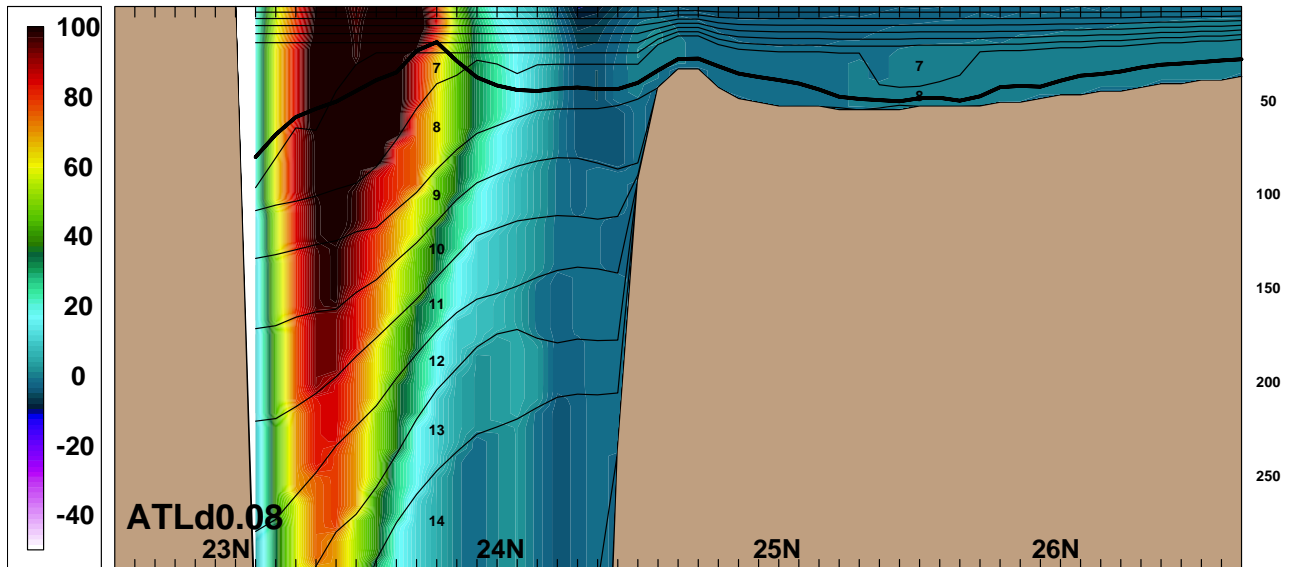
NESTED V-VELOCITY AFTER 180 DAYS

0.1-DAY E-FOLD T-S-p-u-v RELAX

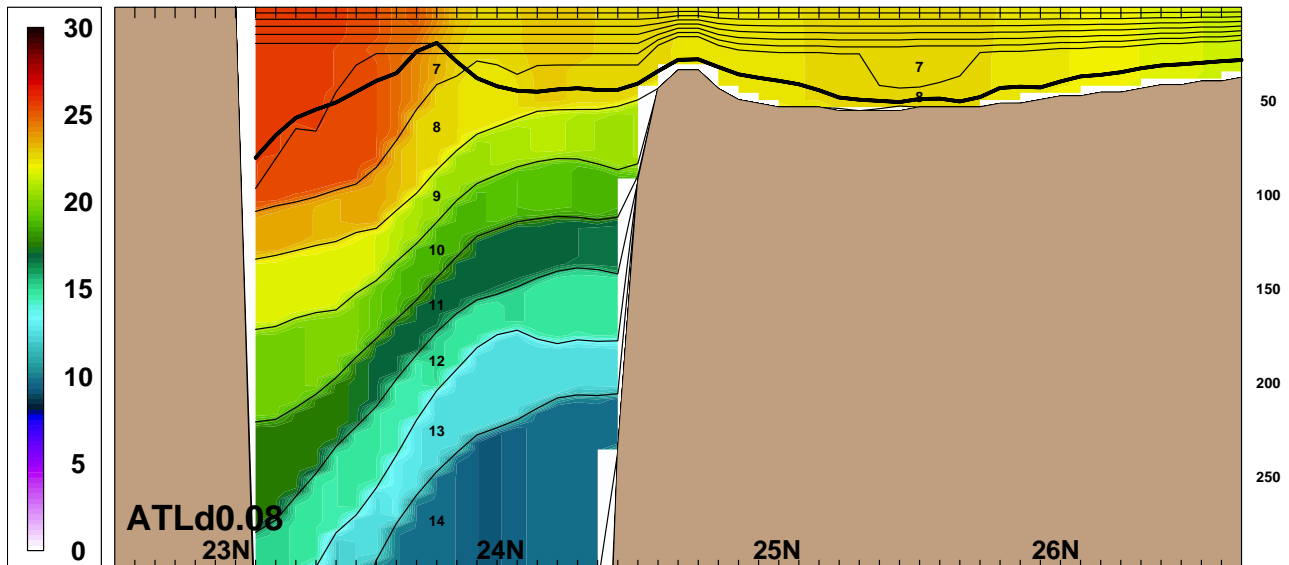


ORIGINAL SECTION AFTER 6 DAYS

u-velocity merid.sec. 83.04w year 6.02 (jan 22) [02.4H]

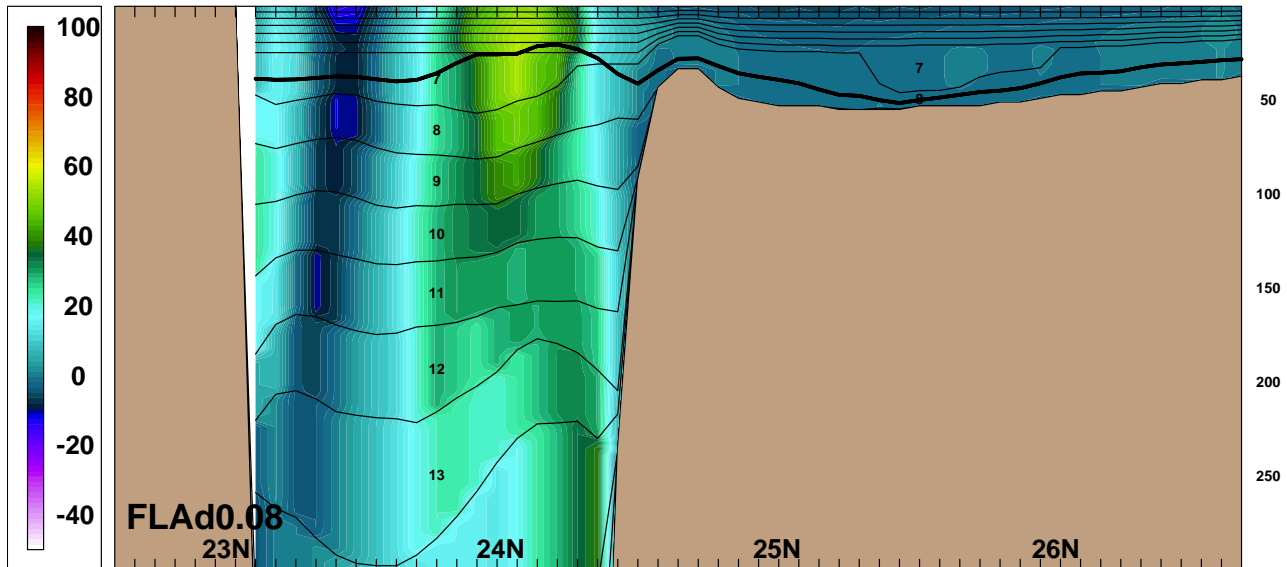


temperature merid.sec. 83.04w year 6.02 (jan 22) [02.4H]

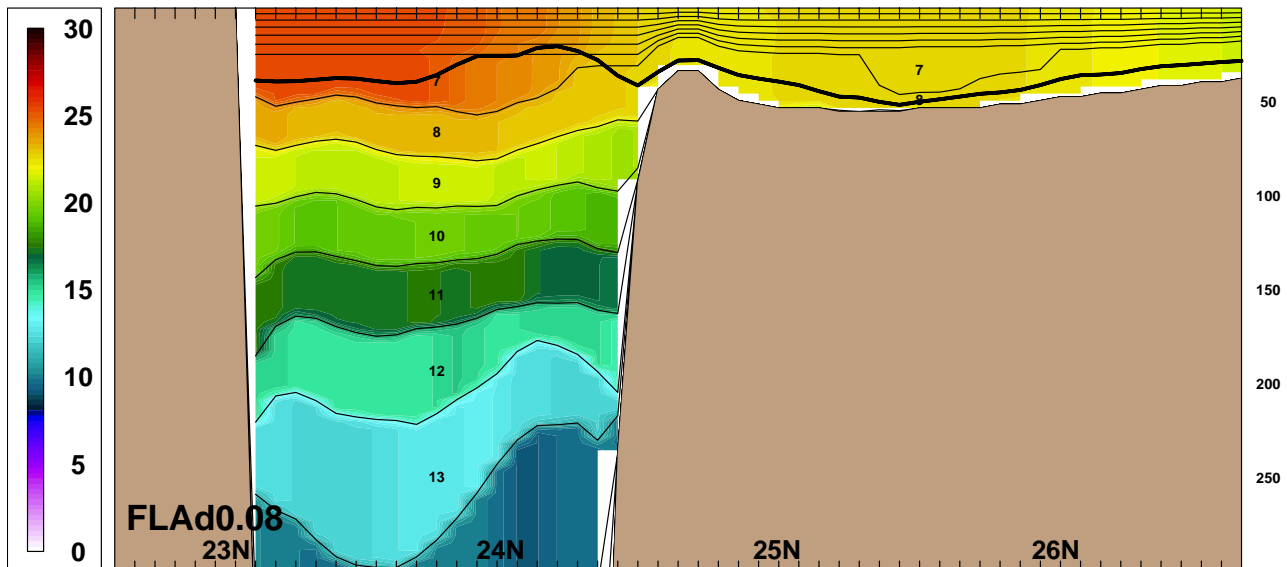


NESTED SECTION AFTER 6 DAYS: 1-DAY E-FOLD T-S-p RELAX

u-velocity merid.sec. 83.04w year 6.02 (jan 22) [01.1H]

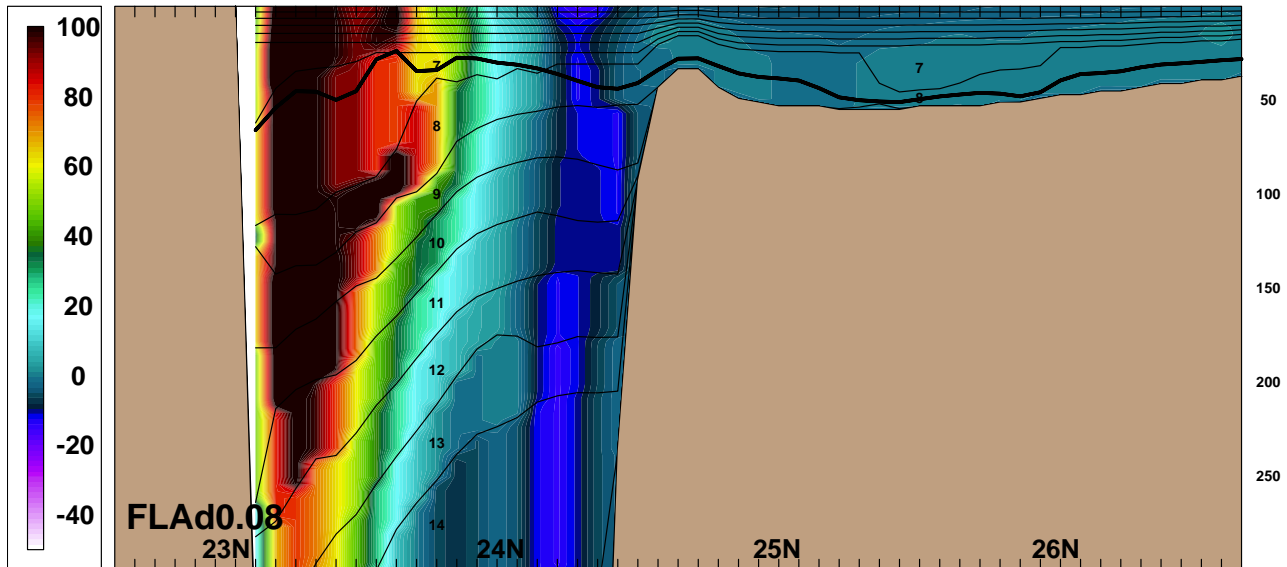


temperature merid.sec. 83.04w year 6.02 (jan 22) [01.1H]

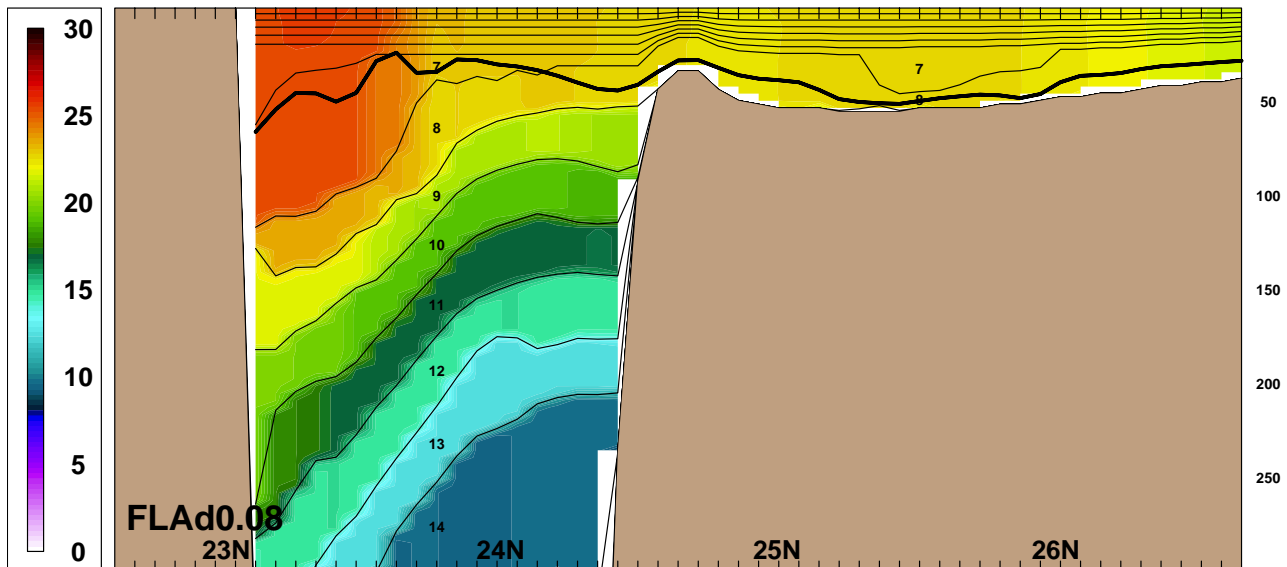


NESTED SECTION AFTER 6 DAYS: 0.1-DAY E-FOLD T-S-p RELAX

u-velocity merid.sec. 83.04w year 6.02 (jan 22) [01.3H]

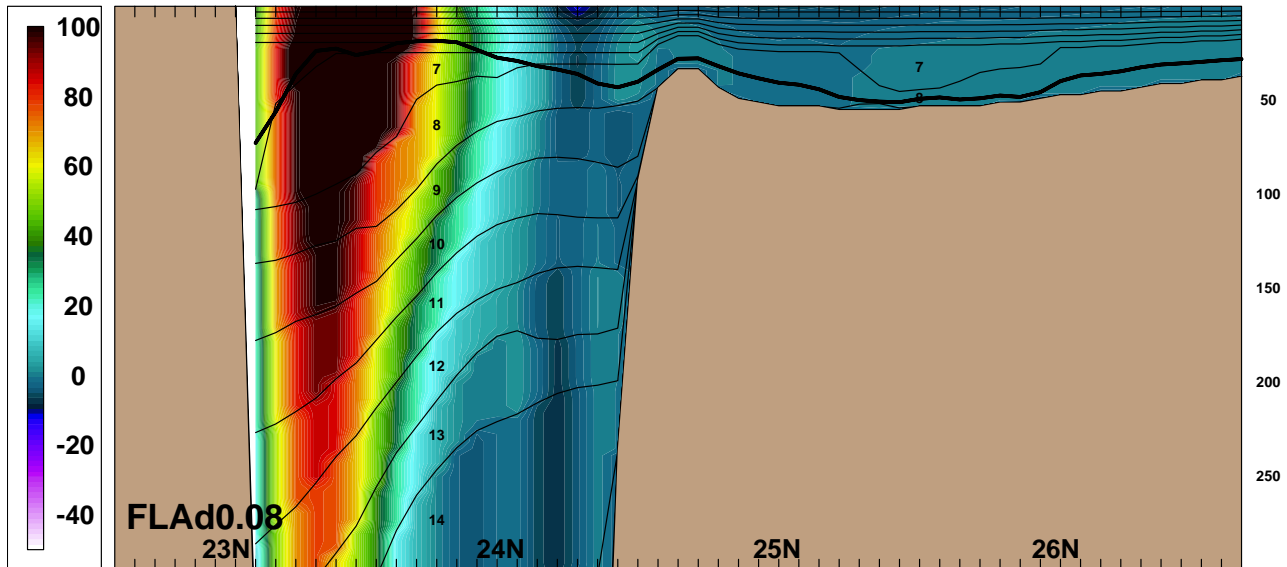


temperature merid.sec. 83.04w year 6.02 (jan 22) [01.3H]

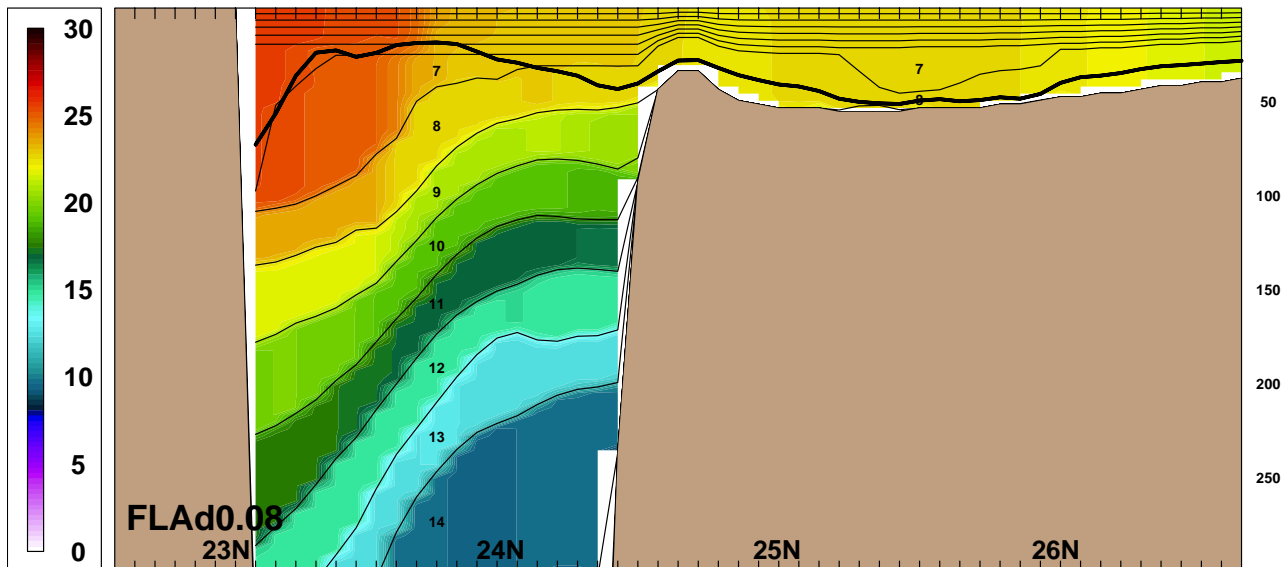


NESTED SECTION AFTER 6 DAYS: 0.1-DAY E-FOLD T-S-p-u-v RELAX

u-velocity merid.sec. 83.04w year 6.02 (jan 22) [01.2H]



temperature merid.sec. 83.04w year 6.02 (jan 22) [01.2H]



Vertical Remapping

- Vertical remapping has two phases
 - Locating the (new, iso-pycnal) layers
 - Interpolating from old to new layers
- These are not completely separable
 - Can't locate layers without allowing for interpolation scheme
- Finite Volume approach allows partial separation
 - Define a profile across original layers
 - Use profile in deciding where to put layers
 - Integrate this profile to get new layer averages
- In HYCOM (hybgen)
 - Highly non-uniform layer thicknesses
 - Same number of layers
 - Most (iso-pycnal) layers don't change
 - Layers don't move more than one grid length(?)
 - Use PCM (Donor Cell) "advection"
 - * Profile is constant across each layer
 - * May be only practical scheme for hybgen

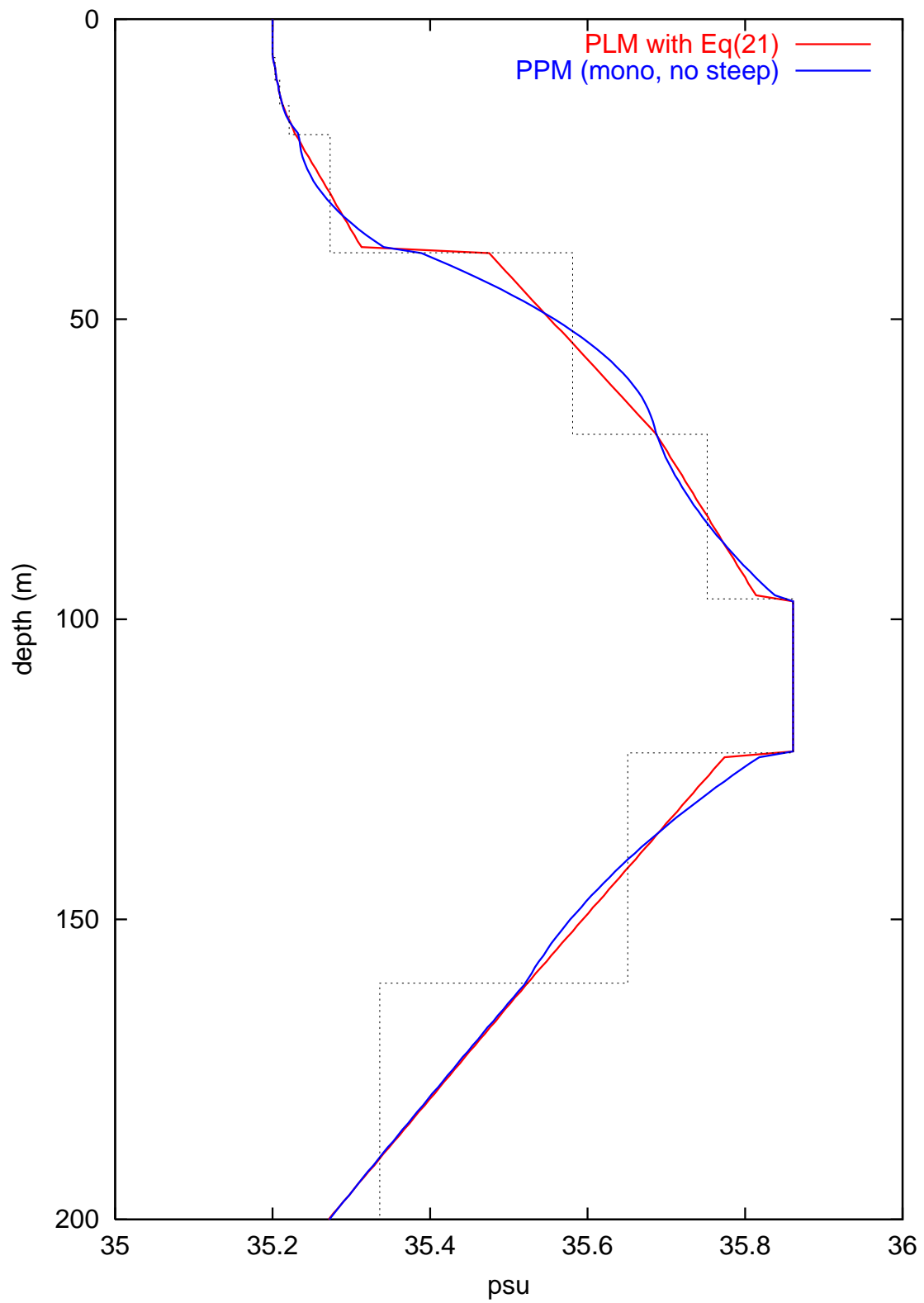
Off-line Vertical Remapping

- Off-line remapping is harder
 - Highly non-uniform layer thicknesses
 - Different number of layers
 - Many layers change location
 - Layers can “move” a long way
- Desirable properties
 - Simple to compute
 - Overall conservation
 - No change if layer is the same
 - * Excludes linear between cell centers
 - No new extrema
- PCM
 - To “diffusive”
 - Lowest order of a family (PLM/PQM)
- Piecewise Quadratic Method
 - Quadratic across cell
 - Very popular advection scheme
 - Tested it, but probably overkill

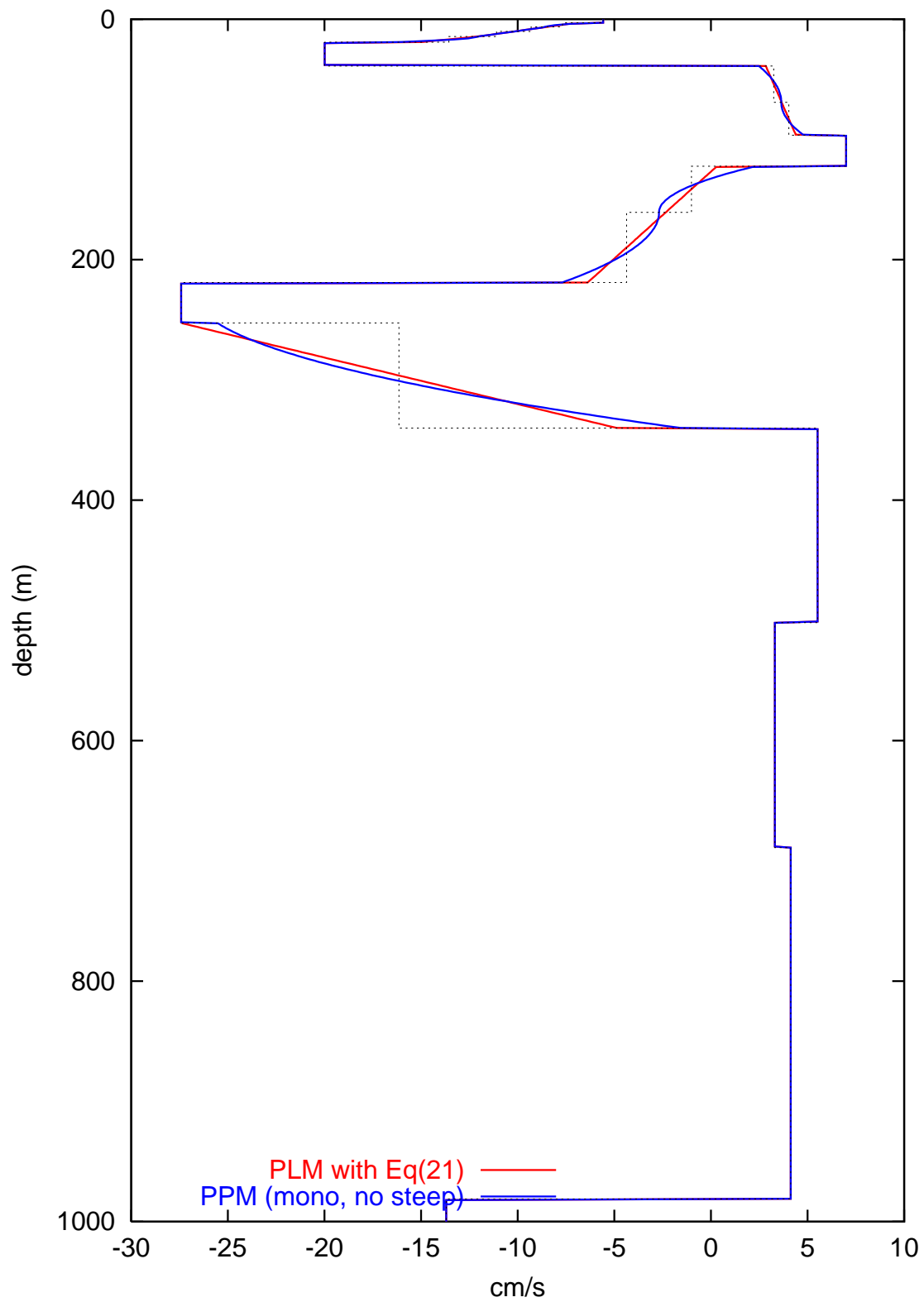
Off-line Vertical Remapping (II)

- Piecewise Linear Method (Van Leer)
 - Linear profile, mean at cell center
 - Discontinuous at cell interfaces
 - Several choices for the slope
 - Tim Campbell developed interpolation variant
 - * Non-uniform layer thickness
 - * Maximize “smoothness” across interfaces
 - Local optimum, global too much work
- Archive to archive remapper
 - Only for fixed target coordinate
 - * Hybrid to sigma-Z
 - Working on iso-pycnals and PLM
- Archive to data3z
 - Returns fields at fixed depths
 - PCM or linear between cell centers
- Single profile remapper
 - fixed depth version (data3z)
 - fixed cell version (PCM or PLM)

Salinity Profile, Year 2000, Day 03, i=251, j=092



V-Velocity Profile, Year 2000, Day 03, i=251, j=092

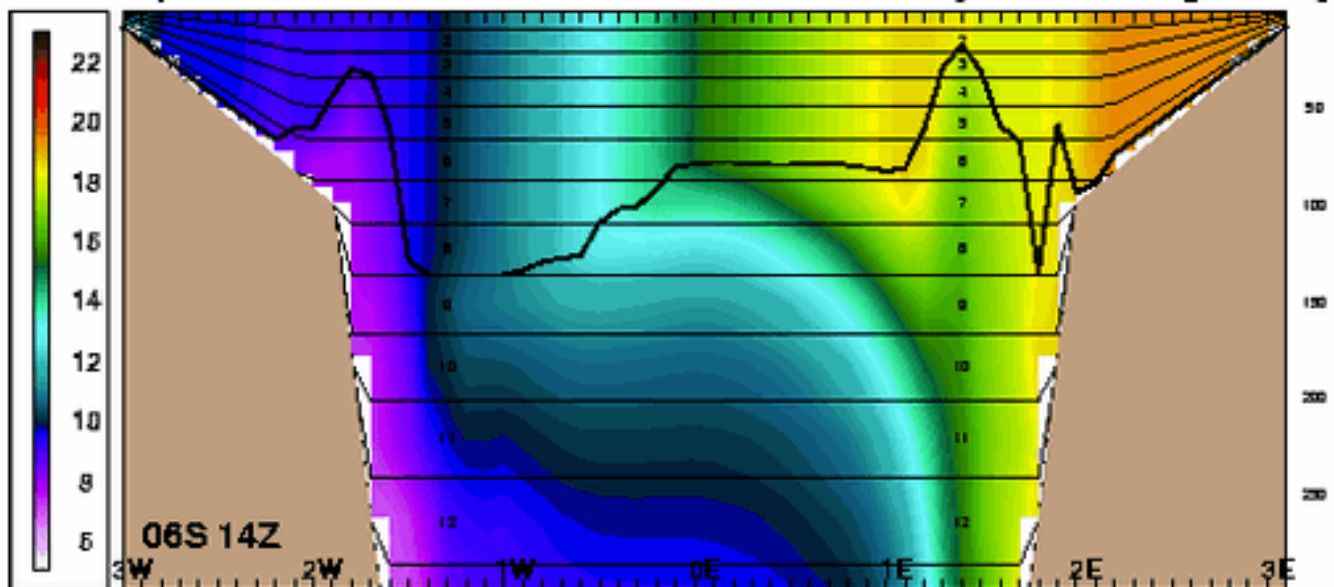


PLM Remapping of Fixed Coordinate Layers

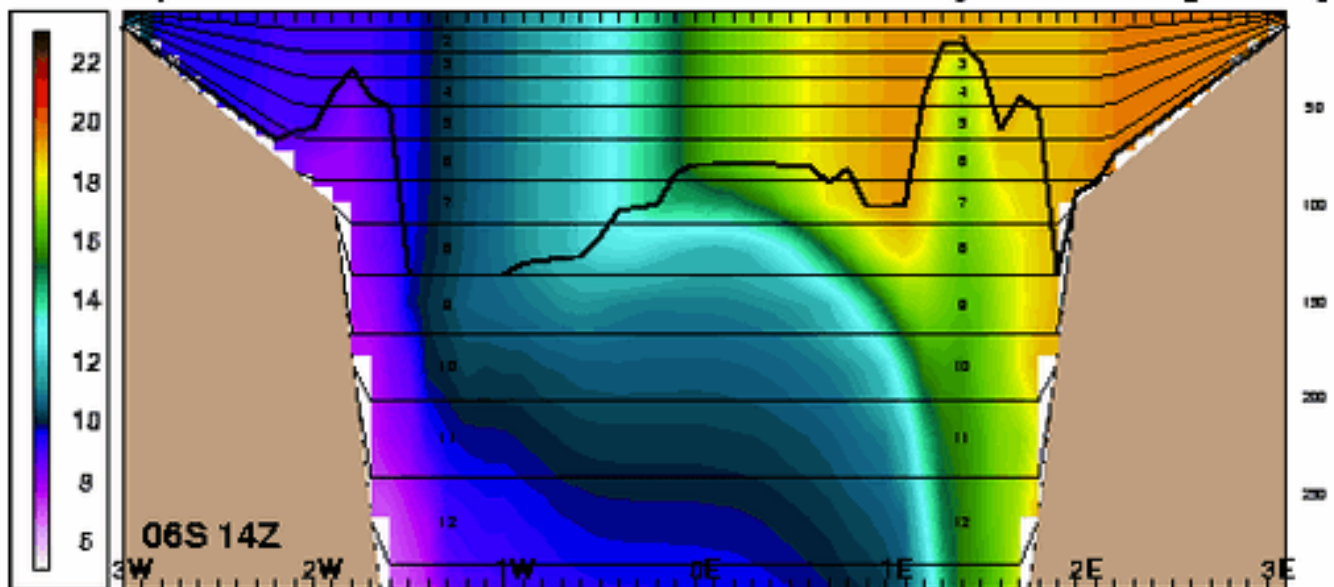
- In HYCOM, hybgen currently uses PCM
- Perfect for iso-pycnal layers
 - Most (iso-pycnal) layers don't change
 - * No remapping, no diffusion
 - Detrainment (thinning) does not change density
 - * Unique to PCM
 - * HYCOM might otherwise be impractical
- Not optimal for fixed coordinates
 - Fixed layers always move
 - PCM is very diffusive
- PCM is a special case of PLM
 - PLM with zero slope
- Use PLM for fixed layers and PCM for iso-pycnals
 - Currently using same scheme for all variables
 - Could use PCM+PLM for density only, or density and salinity only

UP/DOWN-WELLING TEST - SIGMA-Z PCM vs PLM

temperature zonal sec. 29.91n model day: 80.00 [02.7H]

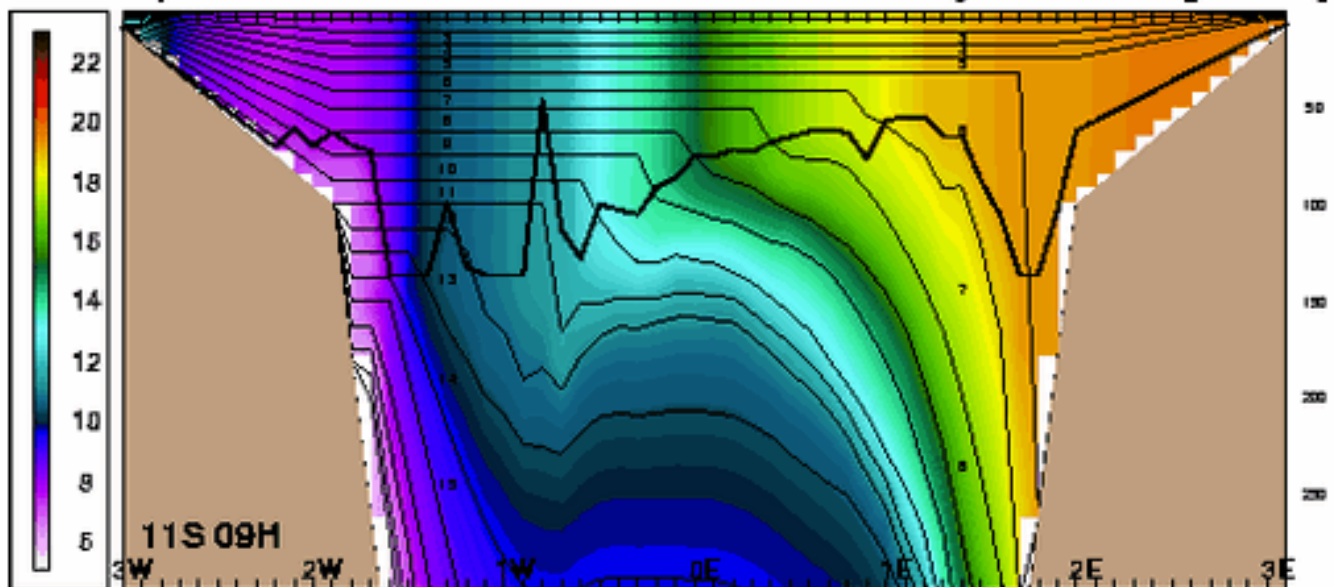


temperature zonal sec. 29.91n model day: 80.00 [06.0H]

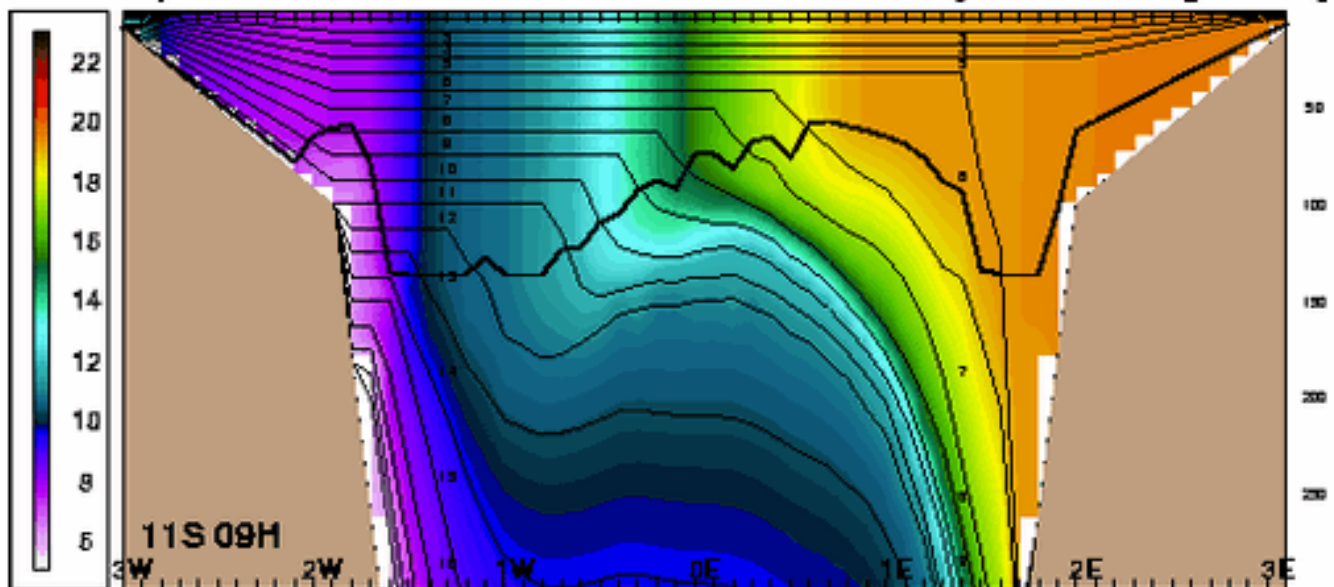


UP/DOWN-WELLING TEST - HYBRID PCM vs PLM+PCM

temperature zonal sec. 29.91n model day: 80.00 [02.8H]

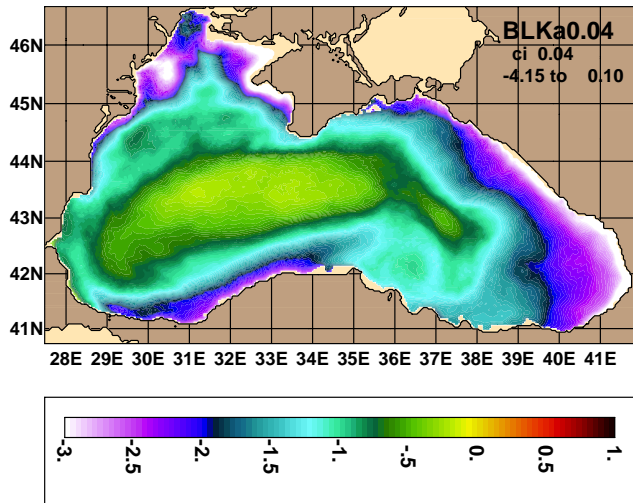


temperature zonal sec. 29.91n model day: 80.00 [06.2H]

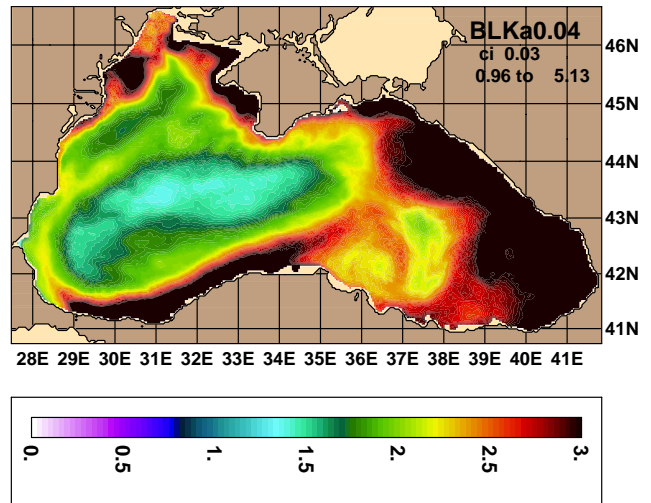


BLACK SEA SST STATISTICS: PCM

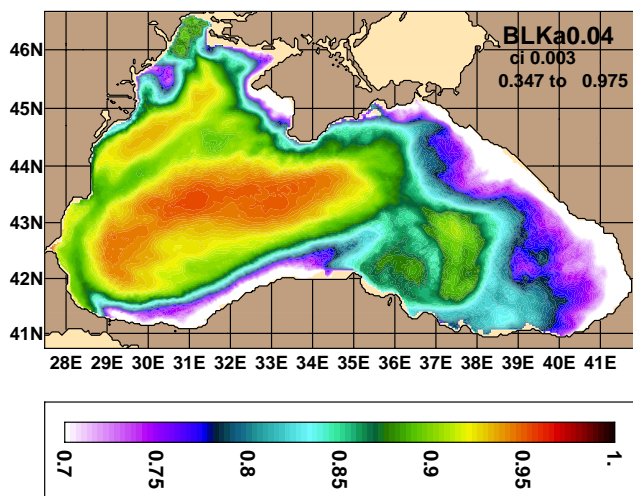
09.1 vs Pathfinder : SST Mean Error (deg C)



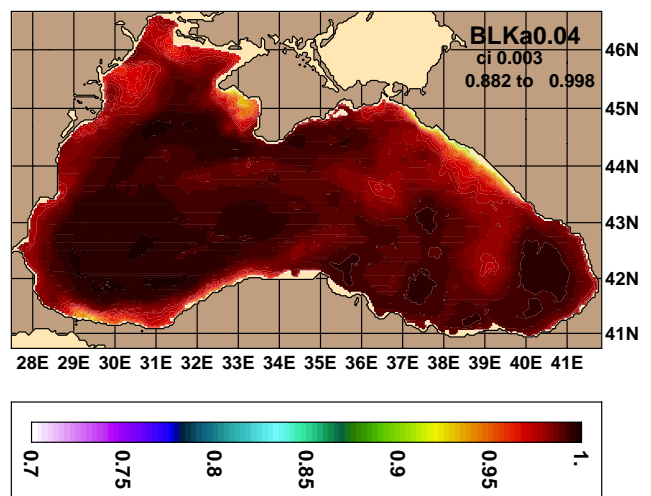
09.1 vs Pathfinder : SST RMS Error (deg C)



09.1 vs Pathfinder : SST Skill Score

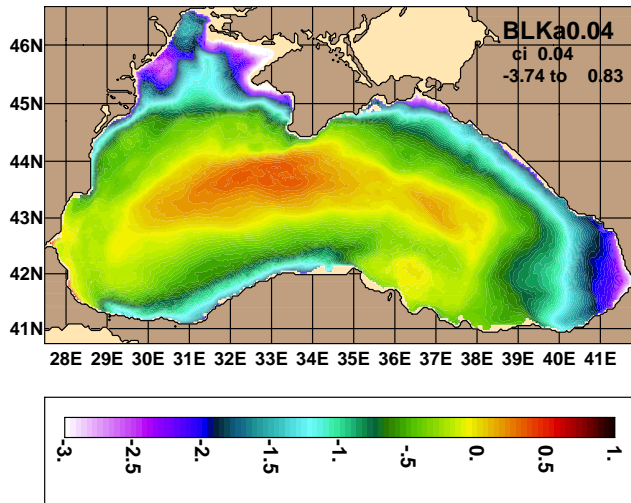


09.1 vs Pathfinder : SST Correlation Coeff.

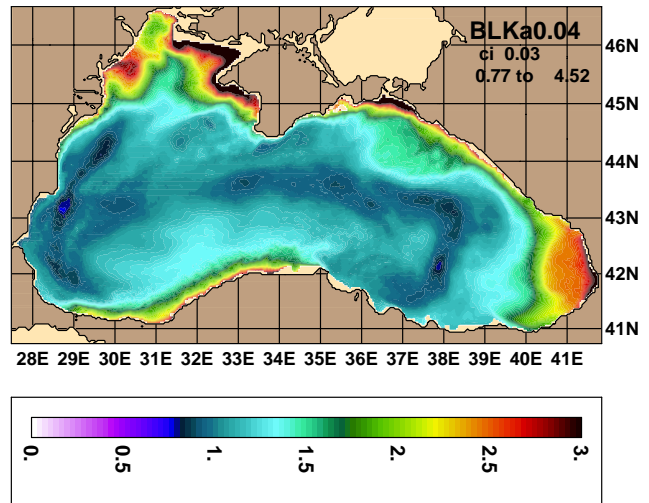


BLACK SEA SST STATISTICS: PLM+PCM

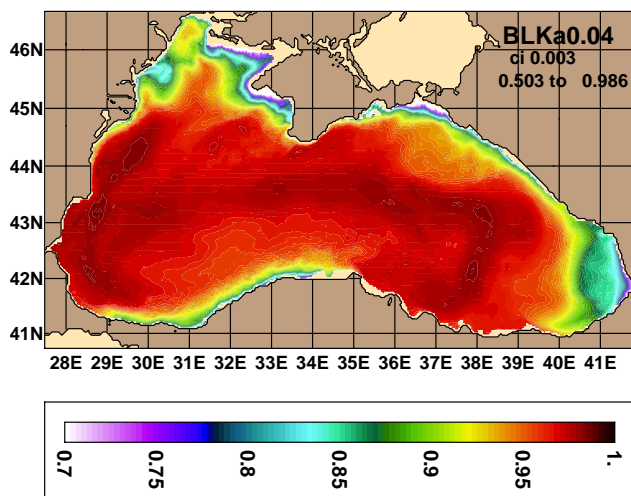
09.5 vs Pathfinder : SST Mean Error (deg C)



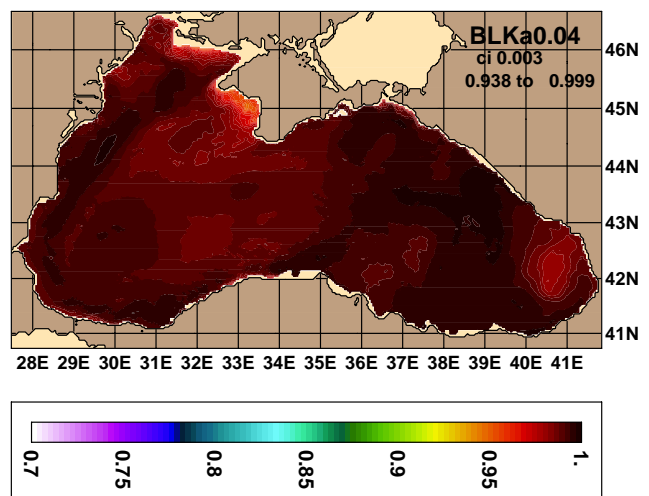
09.5 vs Pathfinder : SST RMS Error (deg C)



09.5 vs Pathfinder : SST Skill Score



09.5 vs Pathfinder : SST Correlation Coeff.



NEW FEATURES OF NEXT RELEASE

- Fully region-independent
 - Compile once, run on any region and any number of processors
- PLM remapping of fixed coordinate layers
- Spatially varying iso-pycnal layer target densities
- GISS mixed-layer model
- Bottom boundary layer in KPP
- Within HYCOM:
 - Drifters
 - Moored buoy sampling
 - Transport section sampling
- NCAR's CCSM Coupler
 - CICE sea-ice model
 - Coupled air-ocean-ice

WISHLIST FOR HYCOM (I)

- Tidal forcing
- Even more mixed-layer models
- Support for data assimilation
- Comprehensive tracer support
 - Within HYCOM and off-line
 - In z-space?
- Use WRF framework for parallelization
 - Weather Research and Forecast model
<http://www.wrf-model.org>
 - Future of all US operational weather centers
 - Automatic compatibility with NASA's ESMF
 - Flexible and asynchronous I/O
- Extended coupler support
 - Alternatives to NCAR's CCSM coupler (ESMF)
 - Bio-geochemical/ecosystem model?
 - Asynchronous I/O?

WISHLIST FOR HYCOM (II)

- Improved/Alternative hybrid remapping (hybgen)?
- Improved/Alternative advection (tsadv)?
- Improved/Alternative split-explicit time scheme?
- Alternative free surface formulation?
 - Currently assume free surface is a small fraction of the total depth
 - * Does this work for coastal domains?
- Atmospheric pressure forcing?
- Rivers (and surface E-P) as mass exchange?